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A PROMISING POWER OPTION -- THE FERCO SILVAGAS™ BIOMASS GASIFICATION PROCESS – OPERATING EXPERIENCE AT THE BURLINGTON GASIFIER

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ABSTRACT

The Burlington Vermont gasifier is the first commercial scale demonstration of the FERCO indirectly heated biomass gasification process. The gasification plant is the largest operation of its type in the US and was the first process to integrate a biomass gasifier with a gas turbine during pilot operations at Battelle's Columbus, OH facilities. The Burlington plant is coupled to the McNeil station of the Burlington Electric Department and is being used to evaluate and demonstrate the gasification technology both as a producer of fuel gas and in a combined cycle with a gas turbine power generation system This paper discusses operating results at the Burlington site including gas cleanup / conditioning observations. Future Energy Resources, the owner of the gasification technology, is developing projects worldwide.

INTRODUCTION

The last two decades have seen a rapid increase in the use of land based gas turbines. To a large extent, this use has been a result of the availability of natural gas at low prices which has in turn facilitated the development of high efficiency low-cost turbines designed to utilize this high value, clean energy source. Recent increases in fuel prices, however, have rekindled interest in alternatives to these natural gas based systems. Transforming solid fuels such as coal or biomass into gas so that they can substitute for natural gas has been an objective of the U.S. DOE for a number of years

The SilvaGas™ gasification process provides a means to use solid biomass fuels as efficient inputs for gas turbine power generation. The use of biomass fuels provides a means to achieve high overall power generation efficiencies without introducing additional greenhouse gases to the environment. Unlike other or biomass gasification processes the SilvaGas™ process produces a gas with a heating value sufficient to allow direct substitution for natural gas in gas turbine engines.

By converting the biomass into this high energy density gaseous fuel, significantly higher power generation efficiencies can be achieved relative to direct combustion based systems (approximately 40% power generation efficiency compared to a maximum of 25% with conventional biomass systems (HHV basis)).

Transforming solid fuels such as coal or biomass into gas so that these higher efficiencies in combined cycle systems can be achieved is a goal of the United States Department of Energy (DOE) and the European Union.

PROCESS BACKGROUND

The Future Energy Resources Corporation (FERCO's) SilvaGas™ biomass gasification process was developed to convert biomass into such a gaseous fuel. Unlike other biomass gasification processes, the FERCO process is not based on starved air combustion, but rather rapidly heats raw biomass in an air free environment to minimize tar formation and create a solid residue char that is used as a heat source for the biomass heating. Significantly less emissions are produced in the process because of the relative ease of treating the high energy density, medium heating value gaseous product.

The process is specifically designed to take advantage of the unique properties of biomass, such as high reactivity, low ash, low sulfur, and high volatile matter. The reactivity of biomass is such that throughputs in excess of 14,600 kg/hr-m^2 (3000 lb/hr-ft^2) can be achieved. In other gasification systems throughput is generally limited to less than 500 kg/hr-m^2 (100 lb/hr-ft^2). Other competing biomass gasification processes were either developed originally for coal gasification or were heavily influenced by coal gasification technology and therefore do not take full advantage of the properties of biomass.

Process Description

The process, shown schematically in Figure 1, uses two circulating fluidized bed reactors as the primary process vessels.

The process, unlike most conventional gasification processes, indirectly heats the incoming biomass to generate a medium heating value (11-14 MJ/Nm^3) gas rather than a low heating value gas. Sand is used as a heat transfer medium to rapidly heat the incoming biomass and convey char from the gasification reactor into the process combustor.

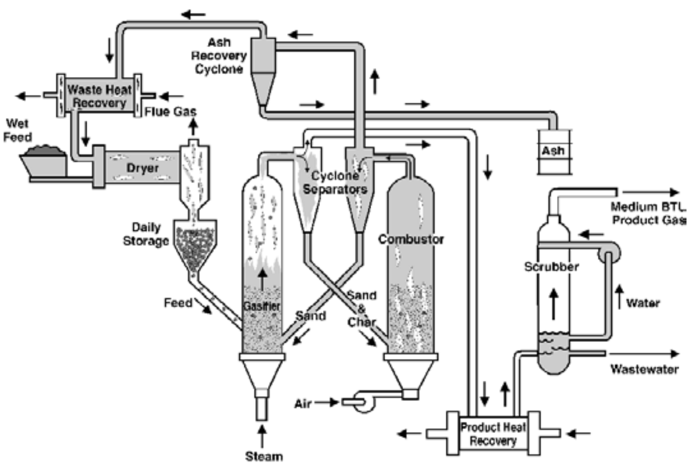

Figure 1. The SilvaGas Process

By applying this indirect heating methodology, the process can:

- Produce a fuel gas that it can be used interchangeably with natural gas or distillate oil
- In IGCC systems, provide efficiency gains of 60% over conventional biomass power plants.
- Reduce greenhouse gas emissions over an order of magnitude compared with current fossil fuel based technologies and over 50% compared to direct combustion of biomass.

Technology Status

The process has been under development since the late 1970's and has been extensively tested with woody biomass, herbaceous crops (switch grass), a prepared RDF from municipal wastes, and a variety of other waste biomass fuels. Testing in the 10 ton per day Process Research Unit (PRU), has coupled a Solar Spartan gas turbine (200 kW) power generation system to the PRU gasifier. This testing demonstrated the feasibility of biomass gasification for power generation, and has provided valuable design data for commercial scale process applications. .

A Commercial Scale Demonstration Plant

The commercial scale demonstration of the SilvaGas™ process is underway at the McNeil Generating station in Burlington, Vermont. A 200 ton per day gasifier produces gas that initially has been used in the existing McNeil power boilers. In subsequent phases of the program, a gas combustion turbine will be installed to accept the product gas from the gasifier and confirm the results from the PRU testing.

INTEGRATION WITH A GAS TURBINE POWER GENERATION SYSTEM

In order to provide the most flexibility to users of the gasification process the gas must be interchangeable with conventional fossil fuels such as natural gas and / or be able to be combined with these conventional fuels to meet fuel commands or operating requirements of the gasification system. Turbine performance must also be similar with the medium heating value gas produced from gasification to that achieved using natural gas or the flexibility of the process is greatly reduced.

Recent testing in the PRU has validated each of these operating scenarios. The Solar Spartan engine integrated with the PRU gasifier was operated at full electrical load utilizing natural gas, biomass derived gas, and a mixture of the two. The Spartan engine used was an older model engine with a relatively low efficiency. The engine operates at approximately 690 kPa (100 psig) and has an inlet air flow rate of 1.9 kg/sec (4.2 lb/sec). Typical data indicate a natural gas consumption of 101 kg/hr (223 lbs/hr) for an electrical output of 195 kW. Combustion quality, as indicated by CO and hydrocarbon figures shown in Table 1 below, is poor by modern standards but not unexpected for a small turbine operating at relatively low combustion temperatures. Because the objective of this study was a comparison between fuels, the lower efficiency of the machine did not have an impact on the overall results obtained. Despite the scale of the turbine, the overall efficiency is somewhat higher than previous predictions.

In order to provide a better understanding of turbine performance, actual performance was compared to predictions(1). Using an assumed compressor efficiency of 59% and a turbine efficiency of 86%, the efficiency predictions are quite near the recorded values. The predicted exhaust temperatures during operation, however, were much lower than predicted (510C (950 F) compared with 343C (650 F) recorded).

The peak power capability of the turbine, and the apparent efficiency, were expected to improve when biogas was fired because the larger quantity of biomass derived gas relative to natural gas amounts to an injection of precompressed working fluid, which bypasses the compressor. Overall, the true efficiency may be slightly reduced when gas compression power is accounted for, although turbine electrical output will still increase. With the load fixed at 195 kW the turbine inlet temperature is expected to be about 771C (1420 F) with biogas and 815C (1500 F) with natural gas, based on the incoming fuel compositions and subject to variations with ambient conditions and turbine conditions. Power generation efficiencies were predicted to be 14.3% and 15.6% at a 95% combustion efficiency for natural gas and biomass derived gas, respectively. Measured values were consistent with these values, but a lower turbine exhaust temperature was measured.

As shown in Table 1, nitrogen oxides in the turbine exhaust emissions are reduced when the mixed fuel is utilized demonstrating improved environmental performance relative to

the baseline natural gas testing. It should be noted that even though the nitrogen oxide levels are greatly reduced with the gas mixture, that unburned hydrocarbon emissions are somewhat higher. Carbon monoxide levels were observed to be about 10% higher than with natural gas alone. Both carbon monoxide and hydrocarbon emissions would be expected to be reduced in higher efficiency combustors typical of more modern gas turbine systems.

Table 1. Turbine Performance and Emissions Biomass Derived Gas Supplemented with Natural Gas

	Nat. Gas	Mix
CO_2, %	1.78	1.75
CO, ppm	457	500
O_2, %	18.1	18.2
NO_x, ppm	20	7
HC, ppm	680	900
Gas Turbine Exhaust C	329	332
Gas Turbine Power, kW	195	195
Main Gas Pressure, psig	90	81
Comb. Gas Pressure, psig	38	58
Natural Gas Flow, % wt	100	33
Biomass Gas Flow, % wt		67

The natural gas used for the tests was typical for central Ohio and had a methane content of 91.6% (volume) and a lower heating value of 36 MJ/Nm^3 (972 Btu/scf). The biomass derived gas had a composition of 28% hydrogen, 12.5% carbon dioxide, 30% carbon monoxide, 11.8% methane, 18.7% nitrogen, and 4.4% C_2's. Its lower heating value was 12.1 MJ/Nm^3 (326 Btu/scf). The nitrogen content of this gas is higher than at commercial scale (discussed below) due to proportionately higher inert gas purges in the PRU.

GAS CONDITIONING

Tar concentrations measured in the product gas from the SilvaGas™ gasifier are typically 16 g/m^3. These tars are highly aromatic in character and are relatively insoluble in water. Partial removal of the tars is possible using conventional water based scrubbing to produce a gas suitable as a co-fired fuel for turbine systems. However, simple water based scrubbing has not been effective in removing condensibles to the levels required for gas turbine applications utilizing biomass derived fuels alone. These scrubbing methods can leave up to 30% of the incoming tar behind in the product gas, but are effective in removing particulate and alkali metal vapors that might otherwise adversely affect turbine performance.

For use as the primary fuel in combined cycle applications, these condensible hydrocarbons must be removed prior to introduction into the gas compression and / or turbine system. Cracking catalysts, such as those used in the petroleum industry, provide one effective option for this cleanup operation. Additionally, a proprietary, low cost, disposable cracking catalyst (DN34) is being developed by FERCO. Both the conventional cracking catalysts and the DN34 conditioning system are being investigated in FERCO's demonstration plant in Burlington, Vermont. The gas cleanup system for turbine applications will include a cracking catalyst reactor followed by wet scrubbing to remove particulates.

COMMERCIAL SCALE DEMONSTRATION OF THE SilvaGasÔ PROCESS

After over 20,000 hours of operation in the PRU, a commercial scale demonstration plant based on the SilvaGas™ process was constructed in Burlington, Vermont. Burlington Electric Department's (BED) McNeil station was selected as the site for this demonstration plant. BED has a long history with biomass based power generation. The McNeil station, at 50 MW, is one of the world's largest wood fired power stations. The McNeil station uses conventional biomass combustion technology, a stoker grate, conventional steam power cycle, and particulate removal using ESP's. BED hopes to improve its generating efficiency by implementing a gasification combined cycle system.

The gasification plant is designed for 182 dry tonnes (200 tons) per day of biomass feed. The program has been conducted in three phases, (1) design, (2) construction and initial operation firing the product gas in the McNeil boiler, and (3) additional gas cleanup, gas compression, and operation of a gas turbine power generation system.

Development Partners

The partners in the development of the process at the McNeil site are FERCO, Burlington Electric, Battelle, the US DOE, and the National Renewable Energy Laboratory (NREL). Battelle engineers invented the process and conducted the initial developments under contract to the US DOE in the early 1980's. In 1992, FERCO purchased the rights to the technology from Battelle and is now the owner of the worldwide rights. In 1999, FERCO was reorganized and refinanced, bringing in additional shareholders including the Turner foundation. FERCO is developing renewable energy projects based on the gasification technology worldwide. These projects will build on the operations at Burlington.

The US DOE and NREL provide valuable technical support to the program along with program management.

Program Goals and Objectives

The development program at McNeil has as its primary objective the demonstration, at commercial scale, of the SilvaGas™ gasification process. The scale selected is sufficiently large so that commercial scale process equipment could be utilized to eliminate so called "pilot plant compromises" in the design. The design of the plant includes all key process systems, with the exception of heat recovery.

The McNeil gasifier construction, shown in Figure 2, was completed in late 1997. After facility completion, an extended startup period began in 1998 and continued into 1999.

The first operation of the plant in full steam gasification occurred in August of 1999. During the startup period, numerous design and operational changes to the plant were necessary to improve the performance of process auxiliary systems. No problems with the process have been encountered throughout the startup period. The process improvements implemented include materials handling, solids separation, and product gas scrubbing.

Figure 2. The Burlington Gasifier

Testing of the process and additional plant modification continued in early 2000. Continuous around-the-clock operation at the plant was achieved in August of 2000 and parametric testing at the site has produced positive operating results consistent with those previously achieved in the PRU. As is the case with all development scale projects, some minor equipment modifications continue at the Burlington site.

OPERATING RESULTS IN VERMONT

Primary among these accomplishments is the demonstration of the production of a product gas with essentially the same composition and production rates as the projections made based on pilot scale data generated at Battelle.

Table 2 illustrates the composition of the product gas generated in the PRU compared to the gas currently being generated in the McNeil gasifier. The verification of the gas composition at commercial scale makes possible the commercial application of the SilvaGas™ process for gas turbine combined cycle operation.

In any biomass gasification system, the moisture content of the biomass feed is important. With partial combustion systems biomass moisture affects the product gas quality; hydrogen and carbon dioxide content increase with fuel moisture, and carbon monoxide decreases changing the heating value, mean molecular weight, and flame speed, as well as affecting the overall gasification efficiency. With the SilvaGas™ process, the gas quality is unaffected by fuel moisture. The gasification reactor must supply additional heat to evaporate the moisture. This heat is reflected in lower product gas volume and decreased process efficiencies however, system response is sufficiently rapid to allow the adjustment of incoming biomass feed rate to compensate for the smaller quantity of product gas produced. To maximize overall process efficiency, it is important to utilize process waste heat to dry the incoming biomass feed. The pending on sites specific conditions, this waste heat can alternatively be used to heat air, raise steam, or for other process heating applications.

The consistency of the SilvaGas™ product is illustrated in Figure 3 below. The figure illustrates operation of the McNeil gasifier over a 24-hour period. During this period the incoming biomass moisture content ranged from 10 percent to more than 50 percent. As is seen, the heating value of the product gas did not change throughout the operating period. Similar results have been obtained during all of the parametric testing conducted at the McNeil gasifier.

Table 2. Comparision of McNeil Gasifier Gas Composition to Battelle Pilot Data

Vol. %	PRU Data	McNeil Data
H_2	17.5	22.0
CO	50.0	44.4
CO_2	9.4	12.2
CH_4	15.5	15.6
C_2H_4	6.0	5.1
C_2H_6	1.1	0.7
HHV		
MJ/Nm^3	18.5	17.3
Btu/scf	499	468

Parametric testing has also included operational periods that confirm the ability of the process to rapidly respond to changes in biomass feed rate without causing changes and product gas composition. Gas composition likewise did not vary when the feedstock was changed from whole tree wood chips to wood pellets.

Gas production rates

Consistency of gas composition provides the foundation for application in gas turbine systems. The other essential element is the gas production rate. PRU testing established a biomass conversion curve that can be used to

evaluate the performance of the McNeil gasifier. Figure 4 illustrates the gas production rates expressed as a fraction of the incoming wood carbon found in the product gas. The McNeil gasifier data (circles) fall well within the data set previously generated in the PRU (diamonds) throughout the operating temperature range tested, 650 to 760C (1200 to 1400F).

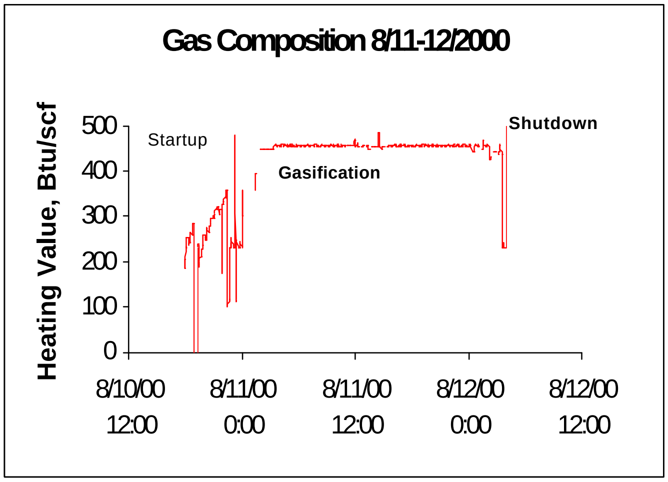

Figure 3. Gas Composition Stability

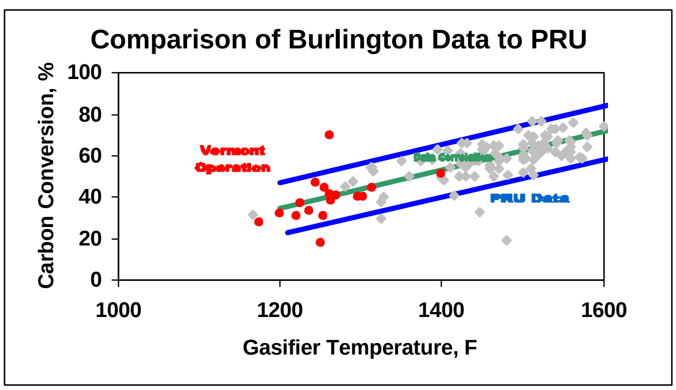

Figure 4. Carbon Conversion Comparison

Reactor Throughput

The throughput of the SilvaGas™ process, as discussed above is significantly higher than competing gasification process. These high throughputs have the impact of providing compact reactor systems that can be readily incorporated into industrial or utility sites. Recent testing at the McNeil gasifier has demonstrated the ability of the process to achieve throughputs far in excess of even those previously predicted. Higher throughputs will result in lower relative capital costs and therefore further improvements in process economics.

The design capacity of the McNeil gasifier is 182 dry tonnes (200 tons) per day. Data generated has shown that throughputs in excess of 320 dry tonnes (350 tons) per day can be achieved with no effect on system performance.

Modification to the plant's feed system are planned to allow throughputs beyond 320 tonnes per day to be evaluated.

Additional Accomplishments

A number of additional accomplishments have been achieved during testing at the McNeil gasifier. These include:

- Product gas generated by the process and supplied to the McNeil station demonstrating the use of the gas as a co-firing fuel, and the generation of power from biomass gasification.
- Product gas supplied the total energy input to the McNeil boiler at minimum load during an interruption in McNeil's wood supply.
- Demonstration that char can be transferred between the process vessels and therefore provide the driving force for the process.
- Demonstration of rapid system response allowing recovery from process upsets within 30 to 45 minutes.
- Startup operations have been improved reducing startup periods from approximately 24 hours down to 6 to 8 hours
- Process design improvements have been identified that will improve efficiency of the process and reduce capital cost.

INTEGRATION INTO A COMBINED CYCLE SYSTEM

To achieve the best overall efficiency, the SilvaGas™ gasification system must be carefully integrated into a combined cycle power generator. This permits effective recovery of heat from the gasifier, the process combustor, and utilizes the exhaust heat from the gas turbine. Such integration has been described in previous publications [2] and is summarized in the following sections.

Figure 5 shows in schematic form how this integration might be achieved. The gas turbine uses a turbine inlet temperature of 1090C (2000F) and a pressure ratio of 10:1. The plant conditions assumed in this case are consistent with current practice for relatively small industrial scale power plants with electrical outputs in the range 5 to 15 MW. The plant has not been optimized and some further improvement in output would certainly be possible. The gross thermal efficiency is 36 percent, and the overall electrical efficiency allowing for gearing and electrical losses is 34.5 percent. After deducting power for auxiliaries, the net output would be about 32 percent. This is a substantial improvement over a wood-fired steam plant operating at the same steam conditions, which would provide

less than half the power at 15 percent efficiency, before deducting auxiliary power.

Industrial power plants frequently operate in a cogeneration mode, supplying both process heat and electrical power. From Figure 5 it can be deduced that the pyrolyzer/gas turbine system could supply electrical power from the gas turbine at about 23 percent efficiency (before auxiliaries) and could also deliver over 60 percent of the input fuel energy as process heat. The overall utilization of thermal energy in this case is around 80 percent, which compares well with cogeneration systems based on natural gas. Where an industrial site has traditionally used biomass waste to produce steam only, usually at less than 80 percent efficiency, a change to cogeneration, with imports of electrical energy, could be very profitable.

When considering biomass as fuel for power generation on a larger scale, say upwards of 25 MW, schemes rather more sophisticated than that shown in figure 3 are appropriate. Consonni and Larson[3] , for example, examined a number of gasification/combined cycle operations based on the use of aeroderivative gas turbines. They assumed a gas turbine inlet temperature (TIT) of 1232C (2250F), and a pressure ratio of 19.4:1 with a steam turbine operating between inlet conditions of 60 atm (900 psi), 450C (842F), and exhaust temperature of 95F (0.82 psi). Using the SilvaGas™ gasifier concept a net efficiency of 42.5 percent based on LHV of the fuel was predicted. It is interesting that direct air blown gasification yielded gases that had insufficient heating value to permit achievement of the same turbine inlet temperature. For these cases the TIT was reduced to 1000C (2012F), resulting in slightly lower net power output. Efficiencies were 45.2 percent for a pressurized gasifier, and 41.9 percent for a near atmospheric pressure gasifier.

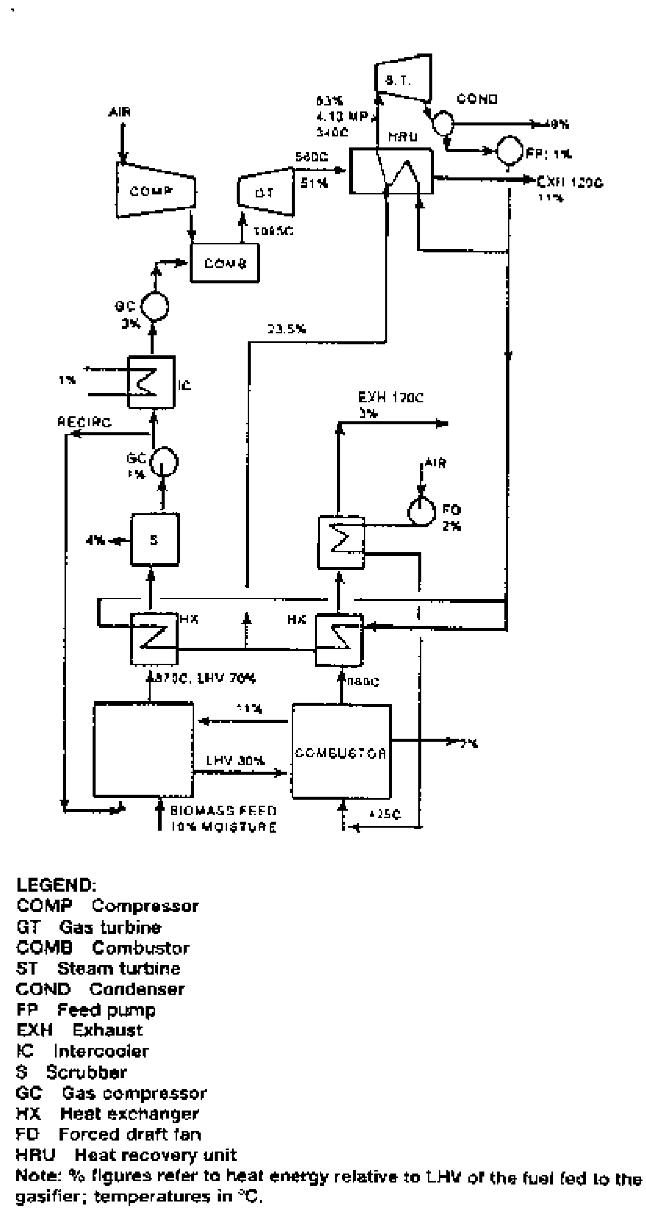

Figure 5. Gasifier combined cycle schematic

PLANNED ACTIVITIES

During the next 12 months, FERCO will be further evaluating gas conditioning in the McNeil gasifier. These studies will focus on both commercially available gas cleanup methods and a proprietary gas cleanup system developed by FERCO and Battelle. This proprietary system has been discussed in previous publications[2]. These studies will also demonstrate the ability of the Burlington gasifier to provide smaller quantities of representative product gas for evaluation of other technologies at the site including chemical synthesis, advanced power systems, or hydrogen generation.

FERCO's development plans also include the design and implementation of advanced power generation at the site.

Development partners will be added to the program team to provide the necessary expertise in gas compression, and power generation. These activities will move the program into its third phase, installation and operation of a gas turbine power generation system.

As a further process improvement, a detailed evaluation of biomass drying options are planned as a part of the McNeil efforts. As discussed above, drying can have a significant impact on the overall process efficiency for biomass gasification combined cycle systems. Of particular interest during the drying evaluation will be the integration of heat recovery with the gasification process. Because of the flexibility of the SilvaGas™ process, a variety of options for integration are possible. Site-specific process requirements may favor the use of one heat recovery option over another such as increased steam production and slightly less power, process air heating with power generation, maximum power generation or combinations of these options.

CONCLUSIONS

The gasification/gas turbine power system provides both power costs and system efficiencies that surpass a biomass direct combustion system, having a power generation process efficiency no higher than 25% with corresponding power costs. Application of the SilvaGas™ process for combined cycle applications has a low risk associated with it since the primary power system components, gas compression, and gas turbine have all been demonstrated commercially with similar fuels. Similarly, operation at the McNeil site has validated the performance of the SilvaGas™ gasification process. The integration of the gasification process with a gas turbine has been demonstrated in the 10 ton per day PRU using a standard turbine. Only minimal modifications (a separate fuel supply system) were necessary to use the medium Btu gas in the gas turbine.

The use of conventional fossil fuels for backup is simplified due to the relatively high heating value of the product gas.

Furthermore, development efforts have confirmed that:

- A medium heating value product gas can be produced from biomass without the use of pure oxygen.
- High biomass throughputs can be achieved in compact reactors
- Nitrogen oxides are significantly reduced relative to natural gas fired systems when the biomass derived gas is utilized in a gas turbine power generation system.
- No extensive preparation of the biomass feedstocks is necessary for the process.

ACKNOWLEDGMENTS

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